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# Record Breaking Increase in Typhoon Rainfall in the Recent Decade: Is it Related to Global Warming?

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# **Record-Breaking Increase in Taiwan Typhoon Rainfall in the Recent Decade: *Is it Related to Global Warming?***

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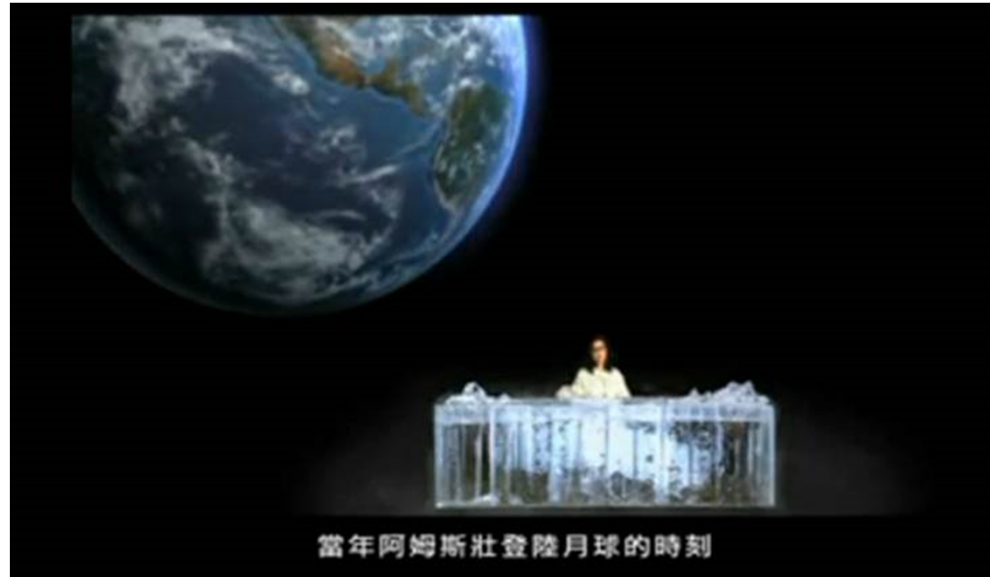


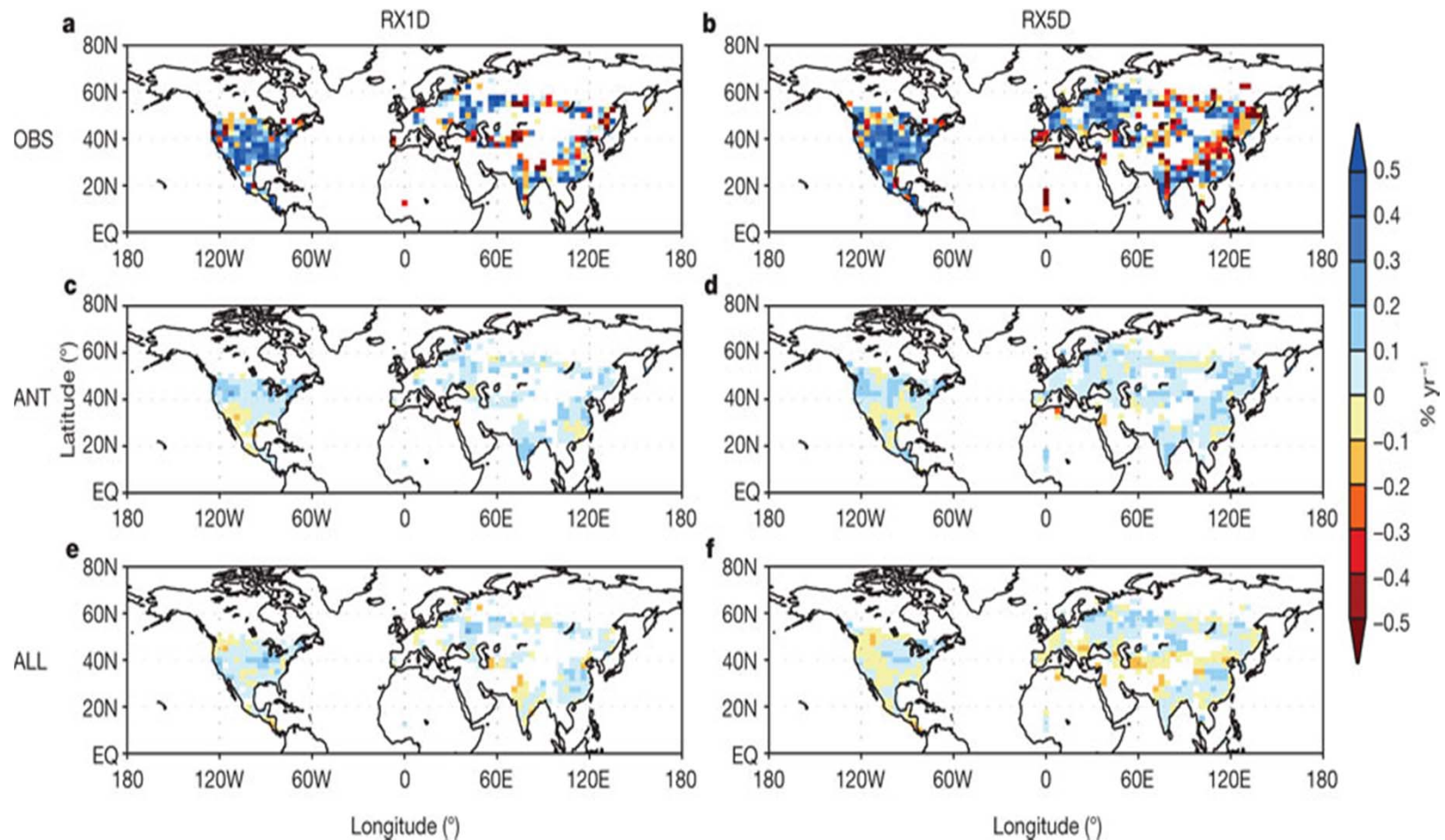
Table 1: The twelve typhoons in 1960-2011 with total rainfall over Taiwan exceeding 3500 mm during the three phases. The eight since 2004 are highlighted.

Rank	Year	Typhoon Name	Total (h)	Rainfall (mm)
<b>1</b>	<b>2009</b>	<b>Morakot</b>	<b>45</b>	<b>8996</b>
<b>2</b>	<b>2001</b>	<b>Nari</b>	<b>75</b>	<b>8108</b>
<b>3</b>	<b>2008</b>	<b>Sinlaku</b>	<b>48</b>	<b>8105</b>
<b>4</b>	<b>2005</b>	<b>Haitang</b>	<b>32</b>	<b>5589</b>
5	1996	Herb	16	4836
6	1989	Sarah	38	4655
7	1960	Shirley	24	4637
<b>8</b>	<b>2007</b>	<b>Krosa</b>	<b>23</b>	<b>3936</b>
<b>9</b>	<b>2004</b>	<b>Mindulle</b>	<b>41</b>	<b>3856</b>
<b>10</b>	<b>2008</b>	<b>Jangmi</b>	<b>25</b>	<b>3800</b>
<b>11</b>	<b>2008</b>	<b>Kalmaegi</b>	<b>23</b>	<b>3763</b>
<b>12</b>	<b>2005</b>	<b>Talim</b>	<b>17</b>	<b>3526</b>

# Introduction

- Global Warming → Increasing vapor capacity → increasing rain intensity and extreme rainfall.
- Climate models simulated increasing trend of extreme rainfall simulated over NH land area; observed over Europe & N. America, but unclear over Asian monsoon region.
- Very large increasing trend of extreme rainfall reported in Taiwan since 1998, attribution to global warming is the subject of ongoing debate (increasing vapor and positive feedback?)

# Geographical distribution of trends of extreme precipitation indices (PI) during 1951–99.



S-K Min *et al. Nature* **470**, 378–381 (2011) doi:10.1038/nature09763

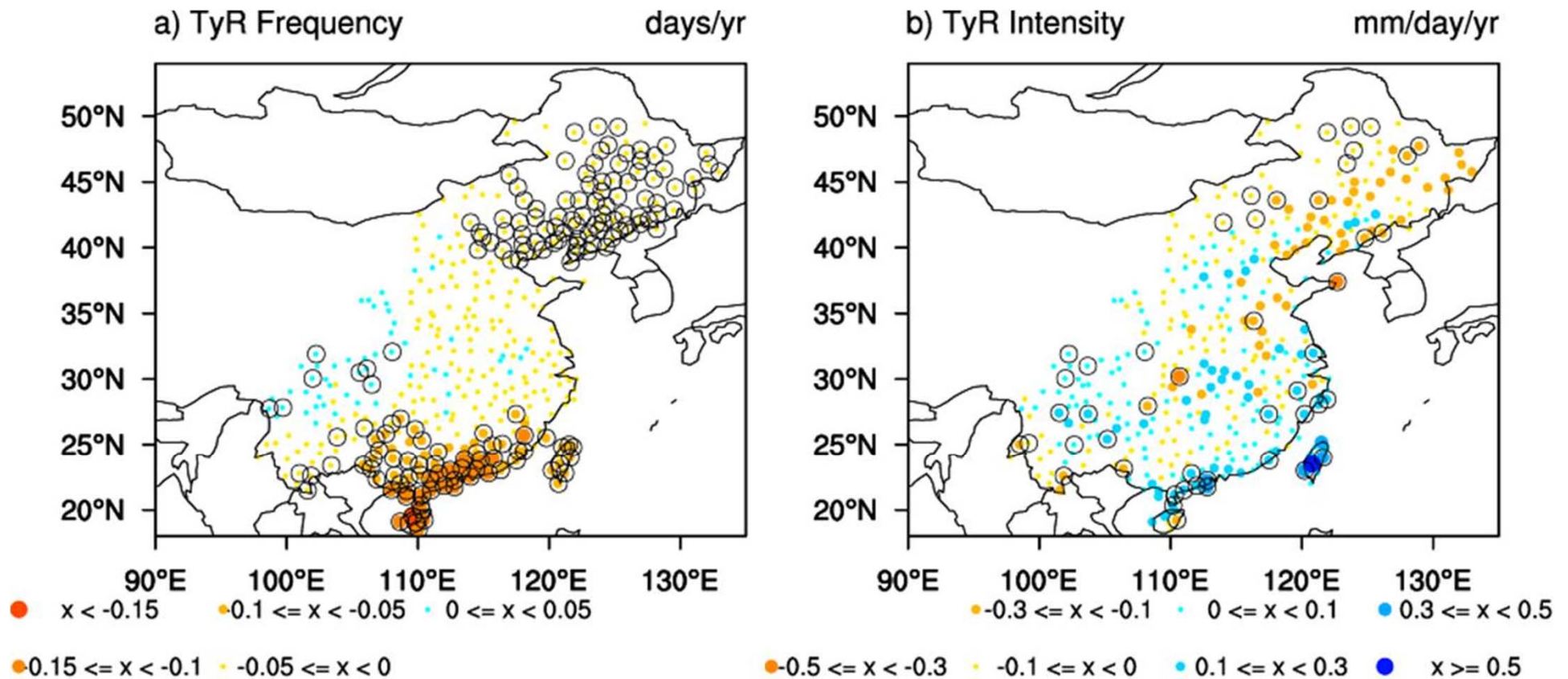
**nature**

# Rainfall in East Asia Summer Monsoon

- Extreme rainfall contributed by both monsoon and Tropical Cyclones (TCs)
- TCs influenced by tropical western North Pacific conditions (upstream of East Asian landmass)
- Extreme rainfall influenced by external factors not part of local thermodynamic conditions

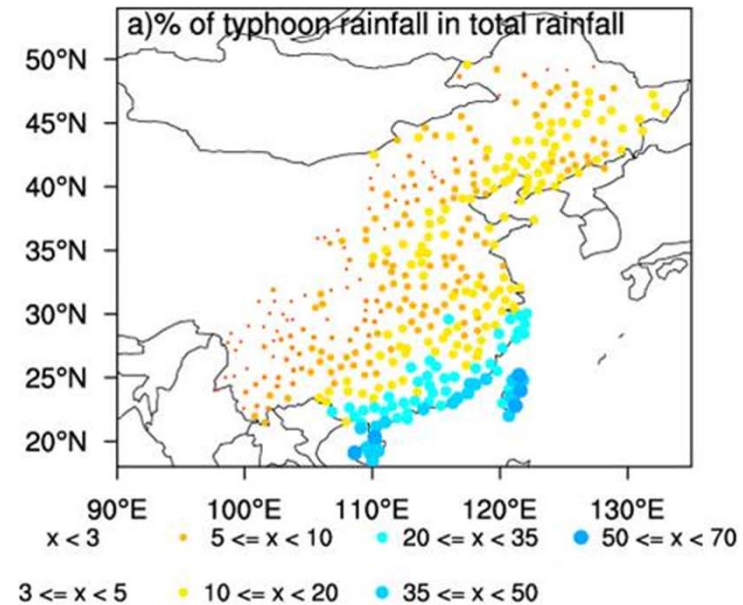


# Typhoon rainfall linear trends

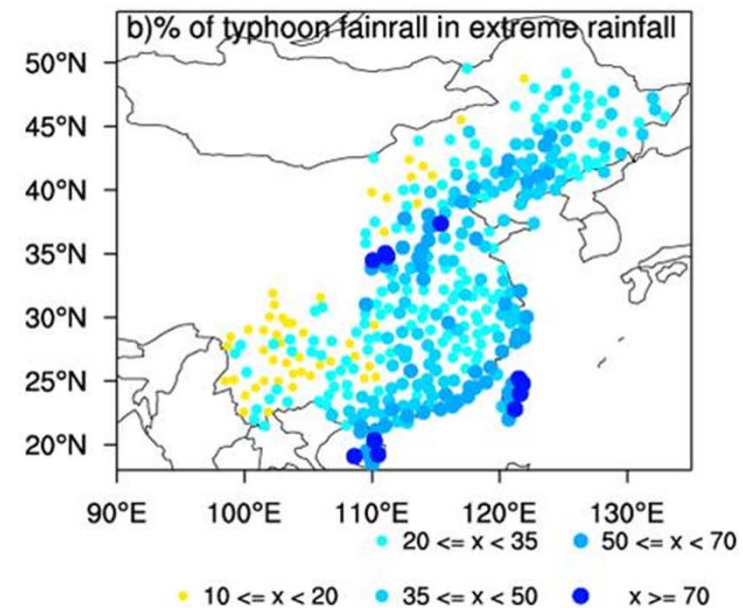


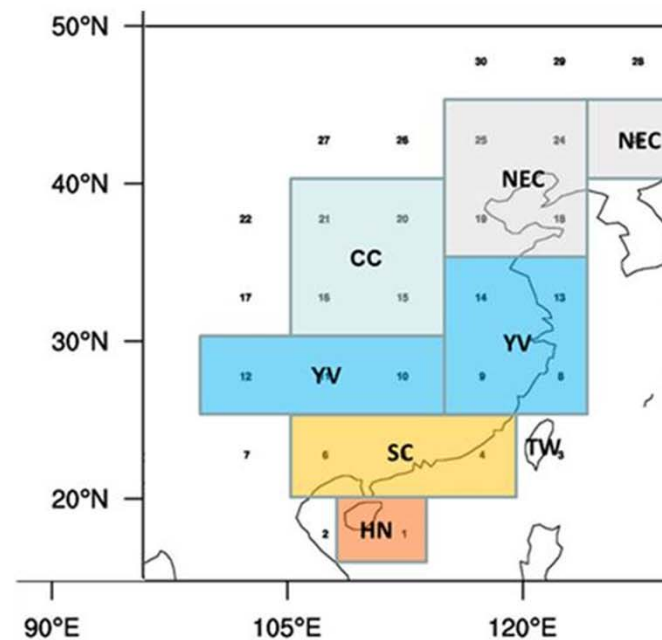
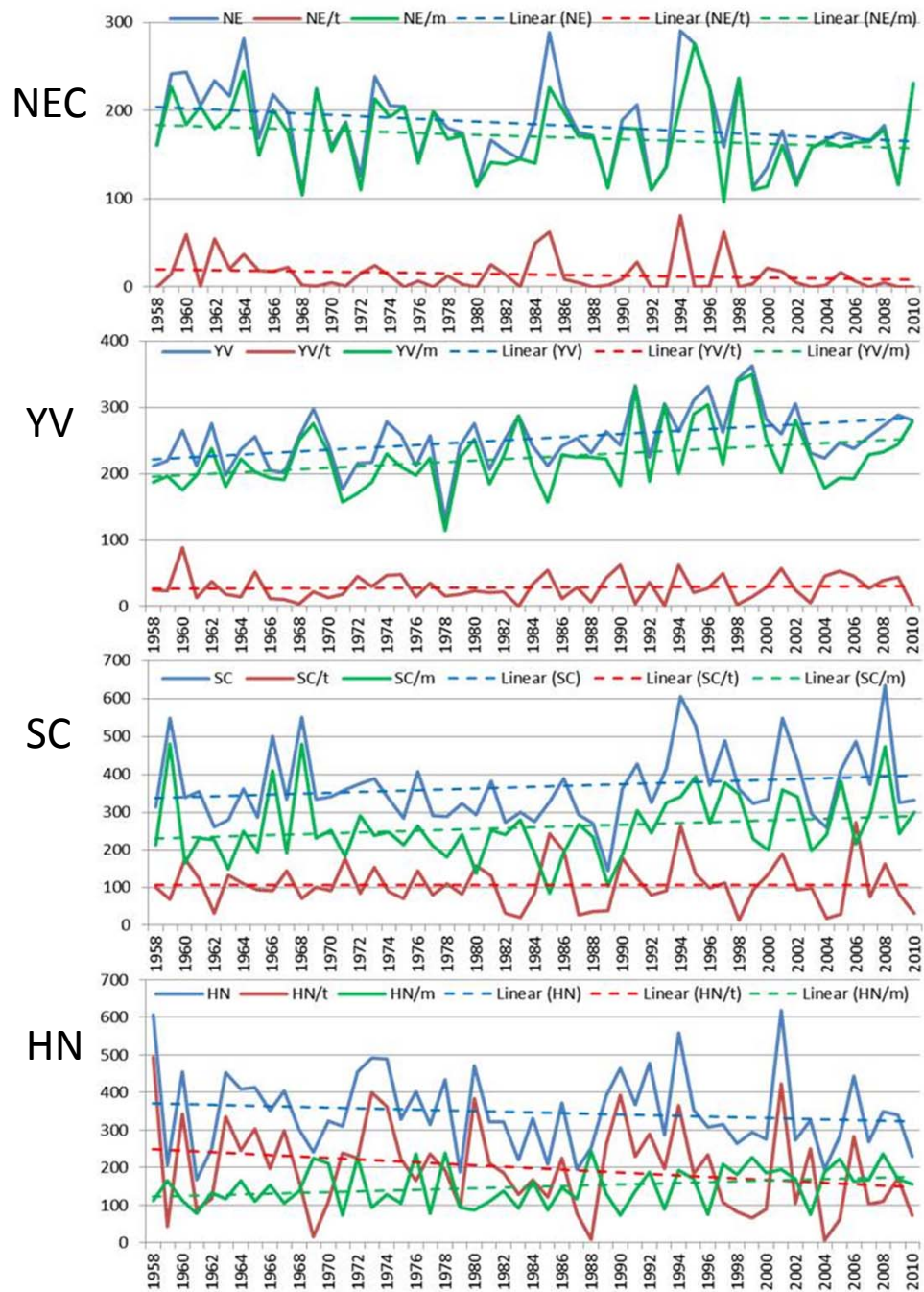


Percentage of TC rainfall  
in Total Rainfall



Percentage of TC rainfall  
in Extreme Rainfall  
(90<sup>th</sup> Percentile)

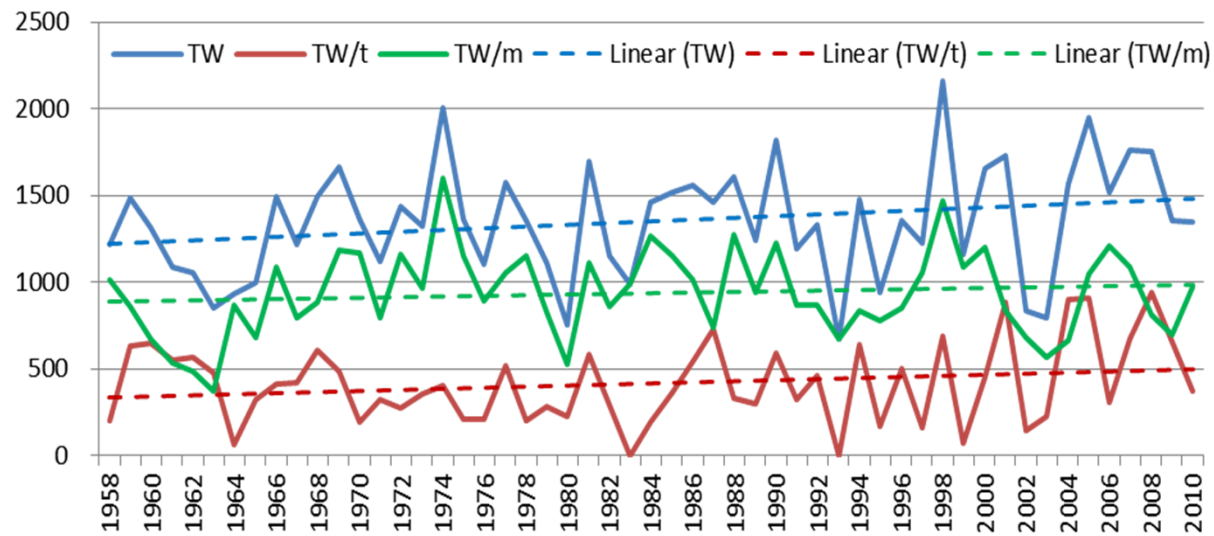




	Total	Monsoon	underestimate
NE China	-21.4%	-16.3%	32%
Central China	6.5%	7.3%	11%
Yangzi Valley	25.1%	26.1%	4%
Southern China	16.5%	23.3%	29%
Hainan Island	-14.8%	35.1%	∞

# Taiwan 90<sup>th</sup> percentile

(by  
events)

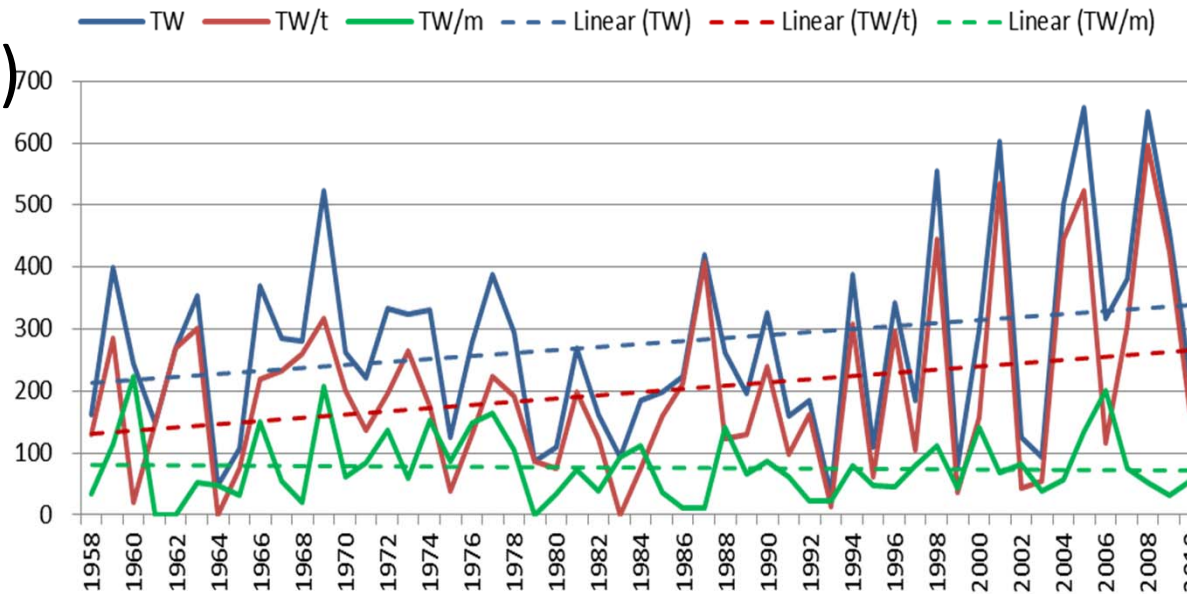


Total 19.5%

Monsoon 10.9%

Overestimate  
~ 79%

(by  
amount)



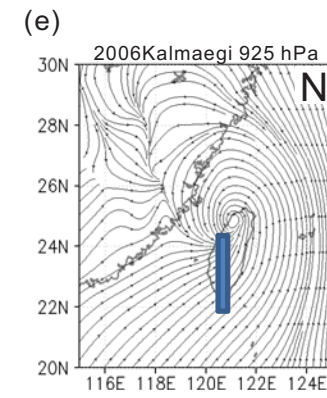
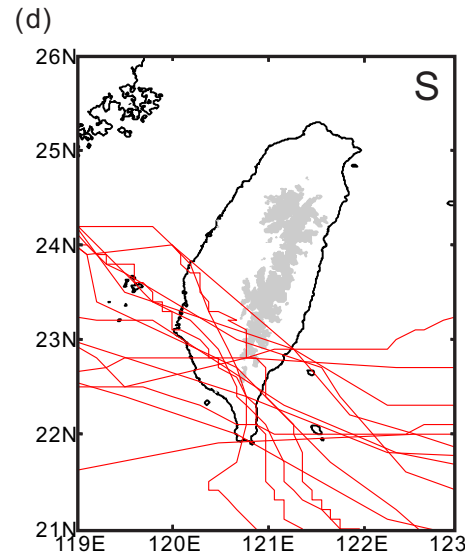
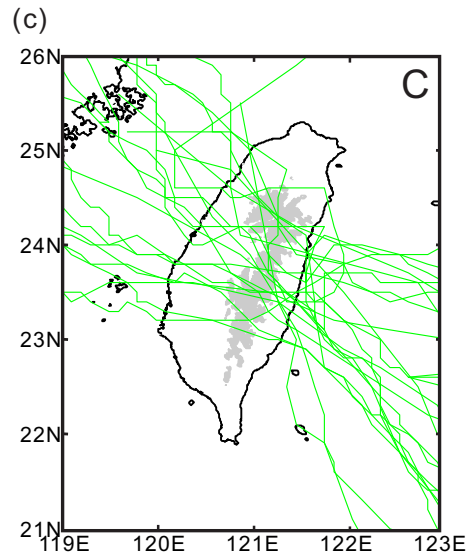
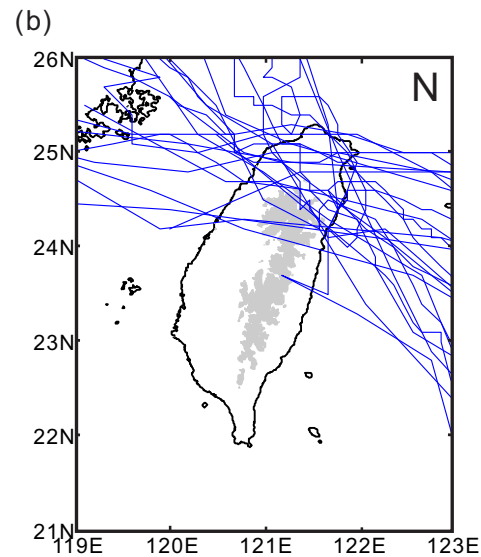
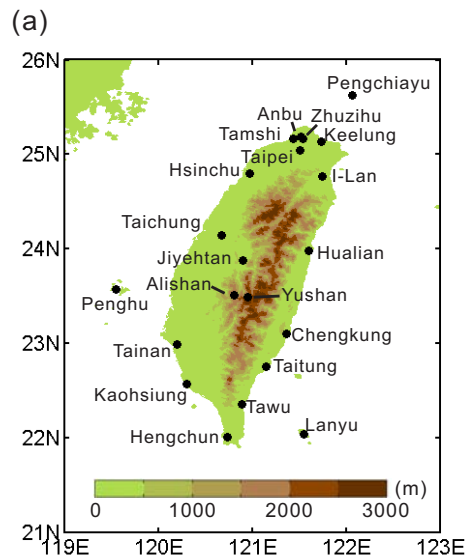
Total 46.2%

Monsoon -12.2%

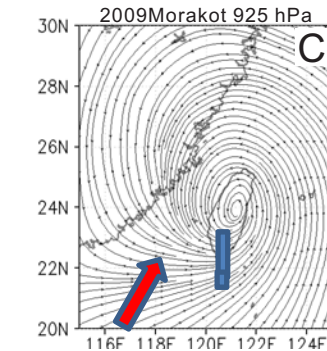
Overestimate  $\infty$

- So most of China Summer Monsoon Area the trend of extreme rainfall was underestimated, because of less TC rainfall. If TC influence is removed, extreme rainfall trend will be more clear.
- Taiwan is an exception.
- What cause Taiwan's typhoon extreme rainfall increase?

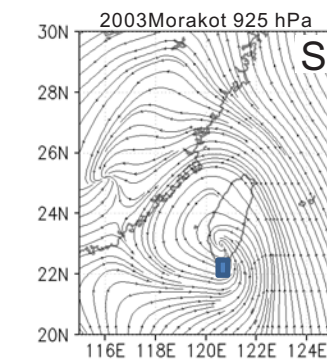




Maximum  
Terrain  
Interaction



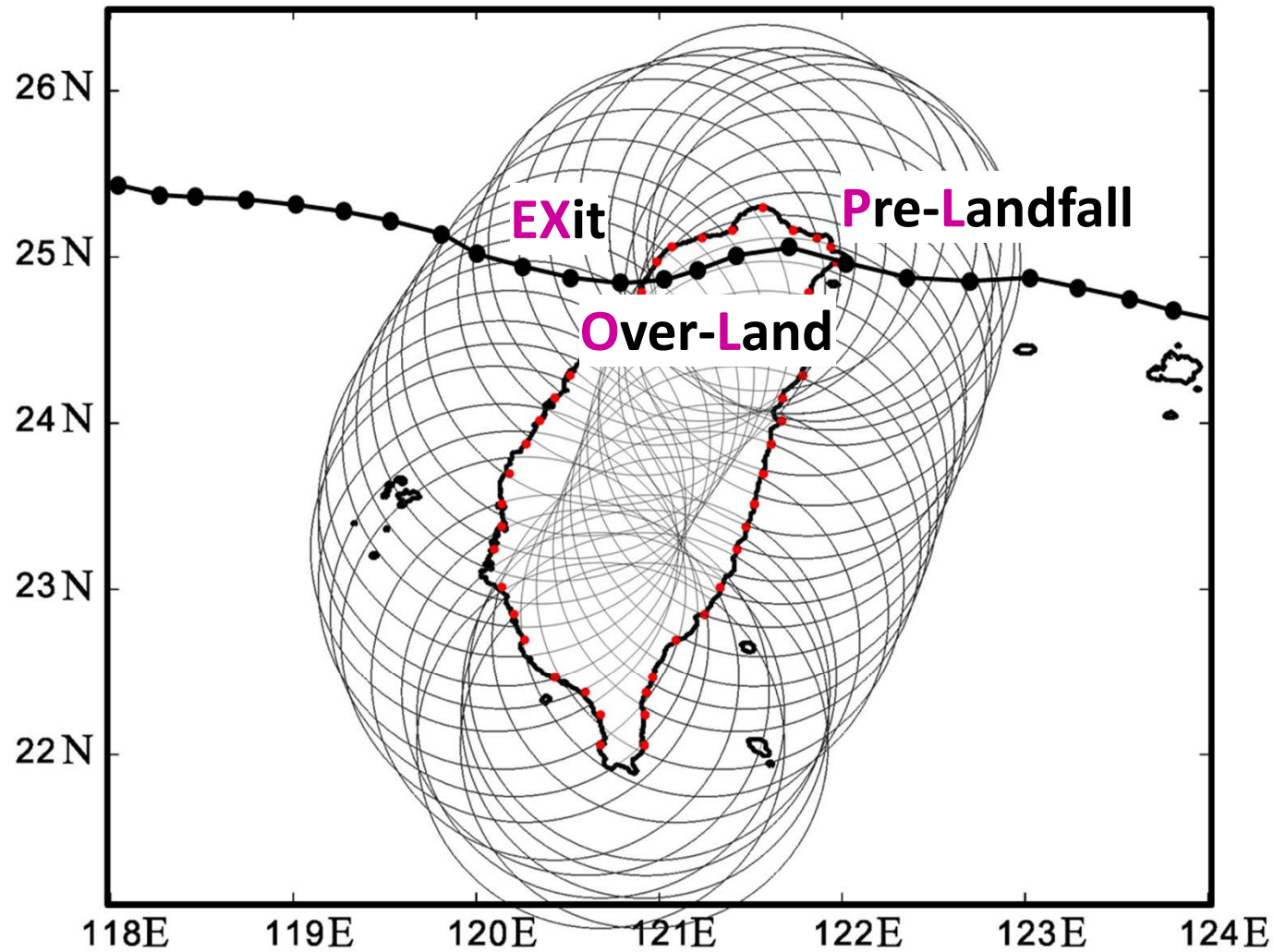
Maximum **SW**  
**monsoon**  
Interaction



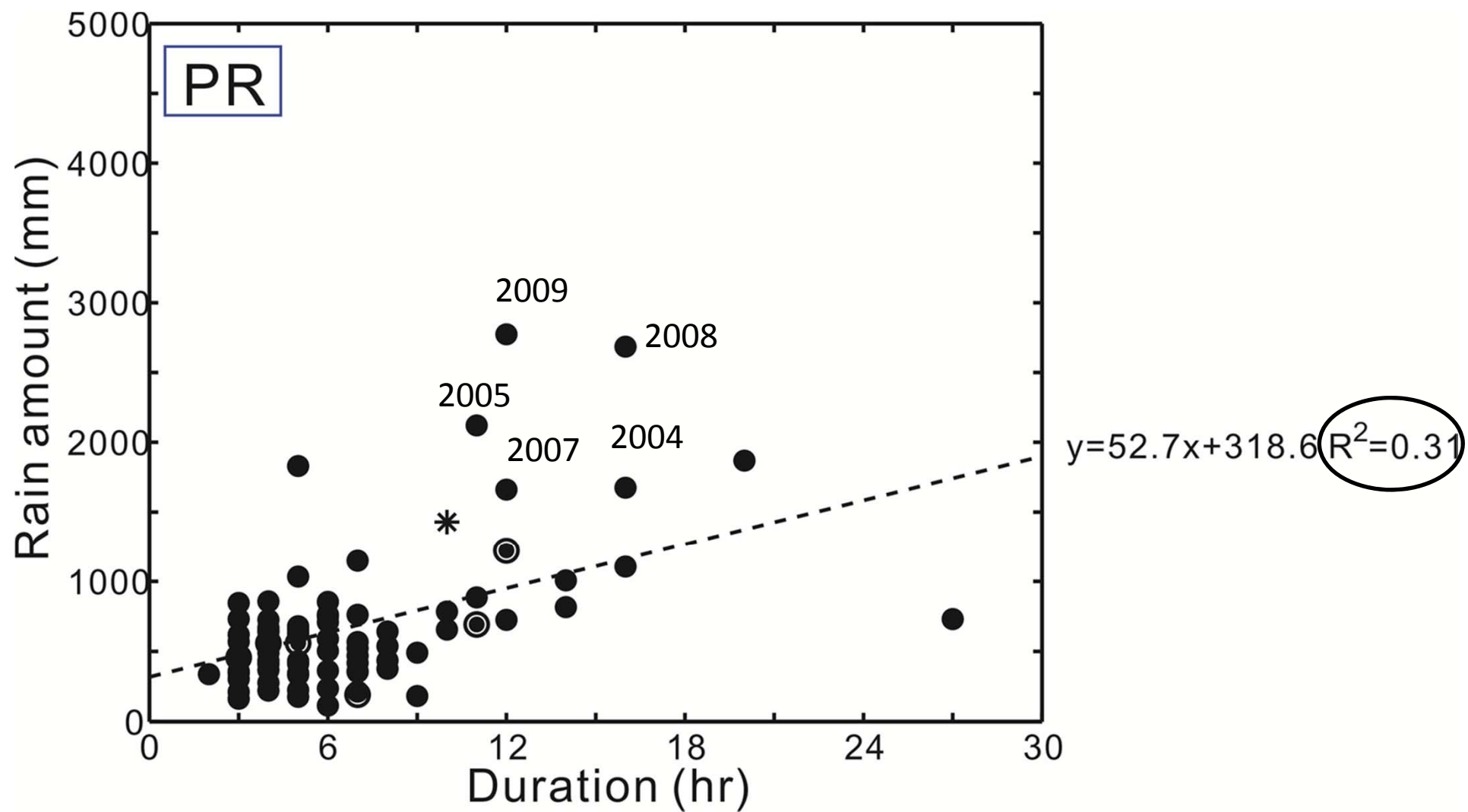
Minimum  
Terrain  
Interaction

1960-2011: 21 hourly stations , 84 landfalling typhoons

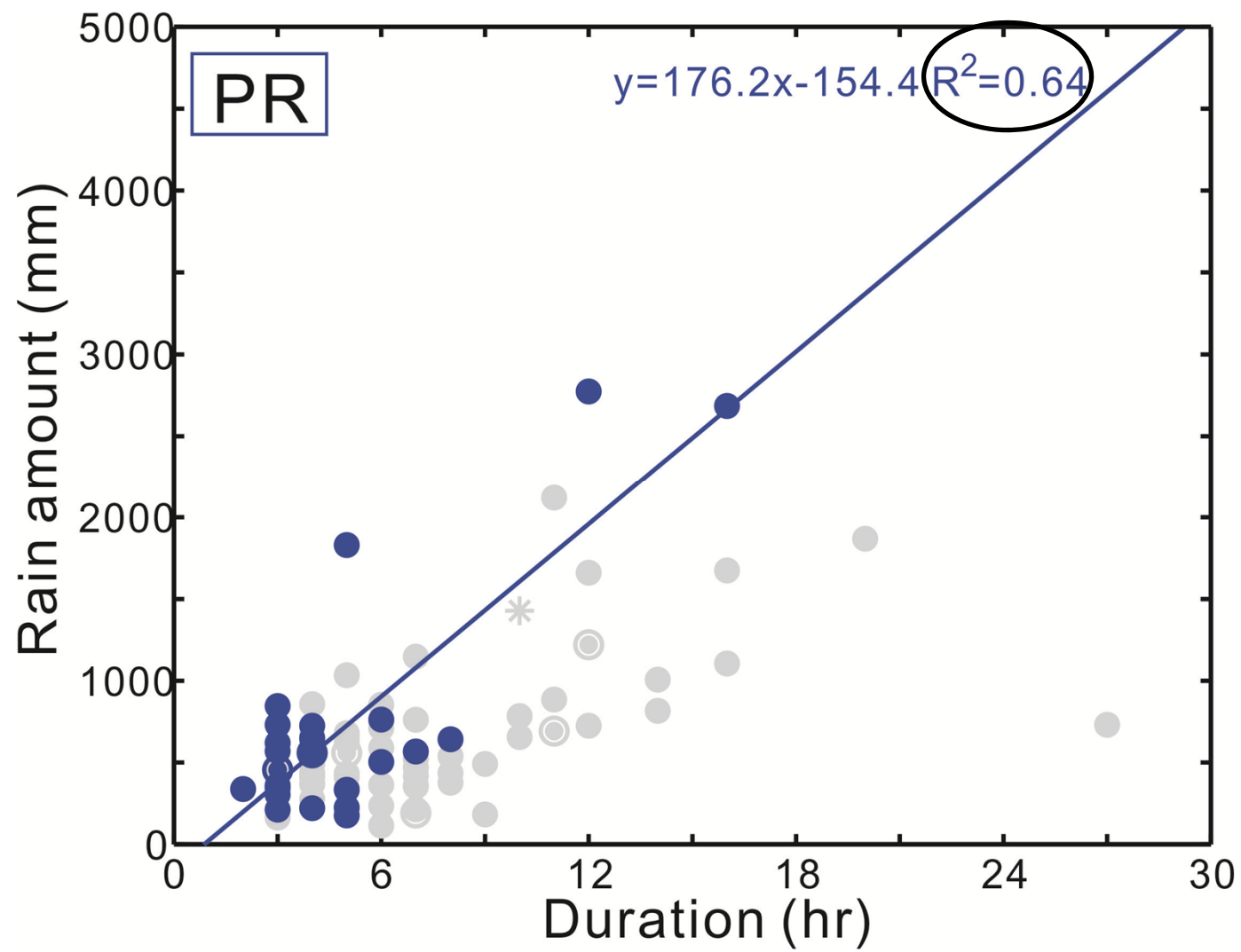
# Typhoon Track Phases

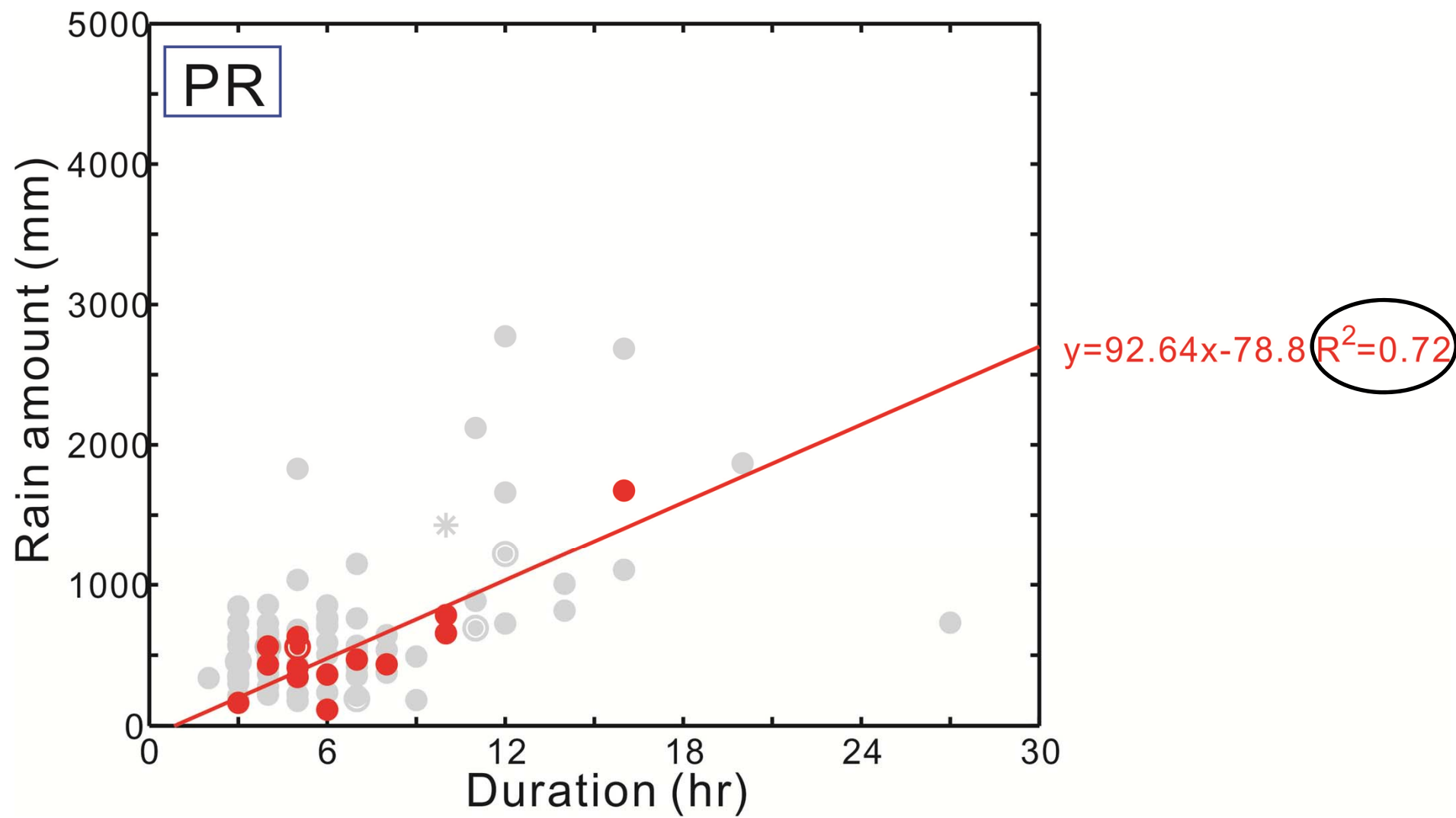


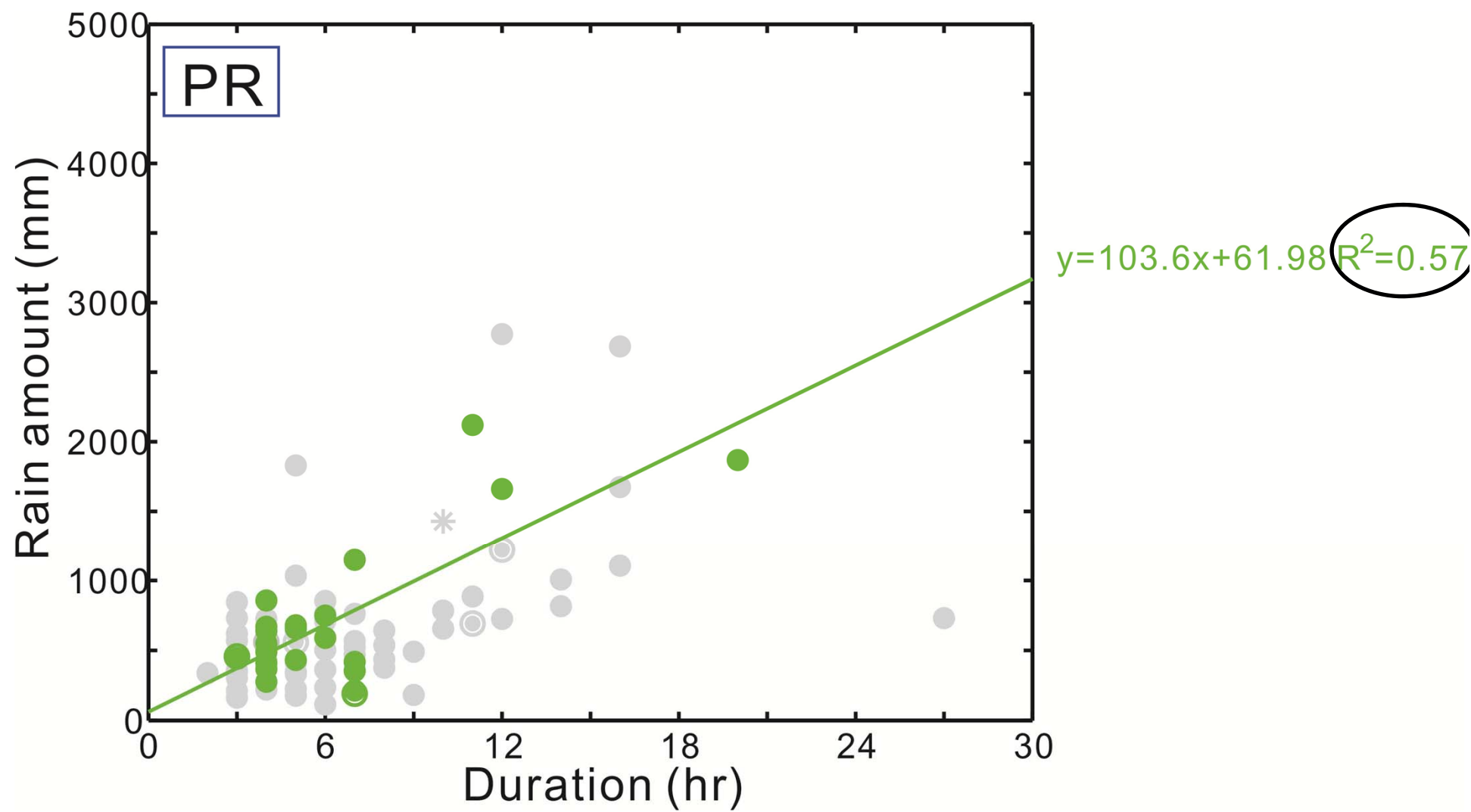
# PRe-Landfall

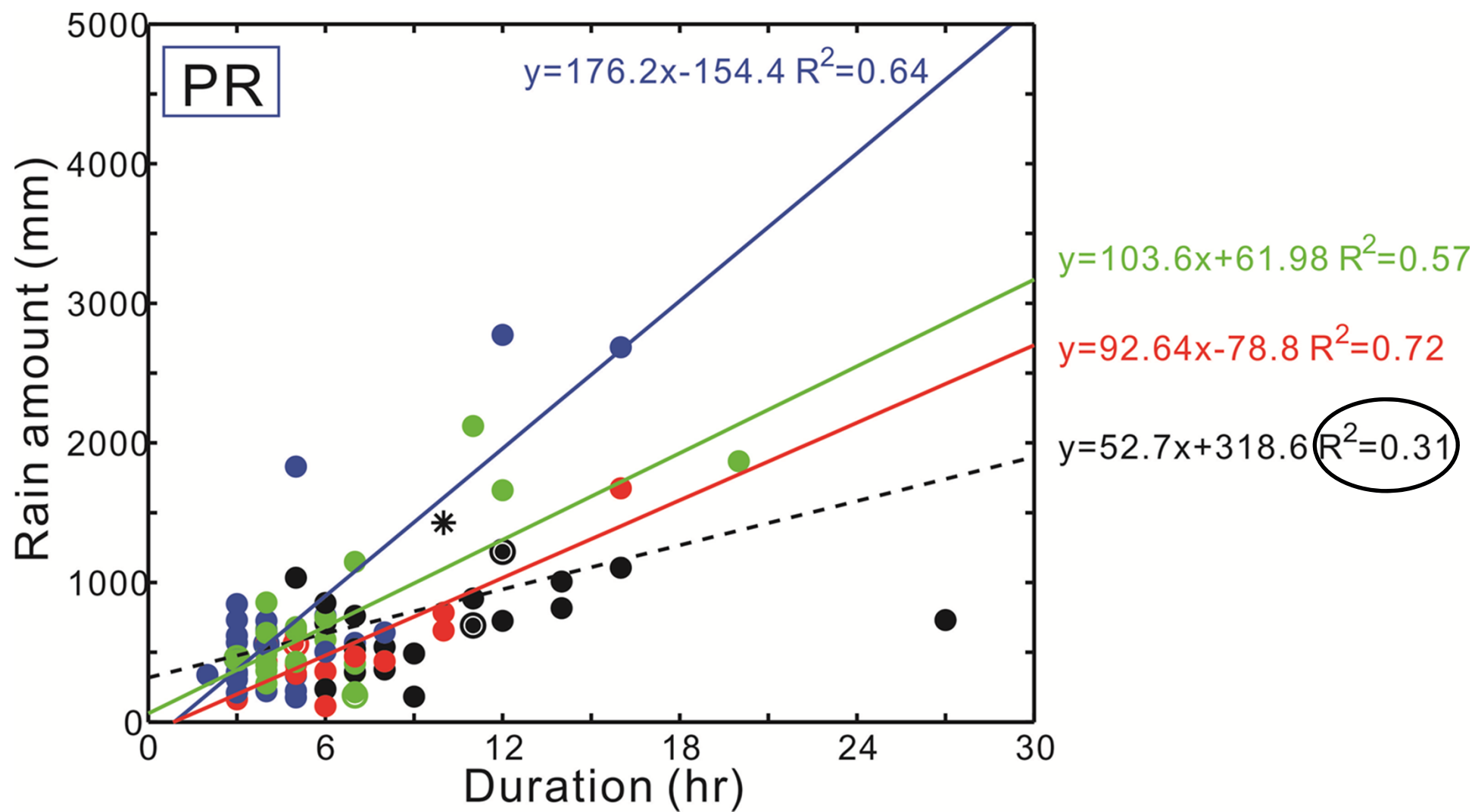


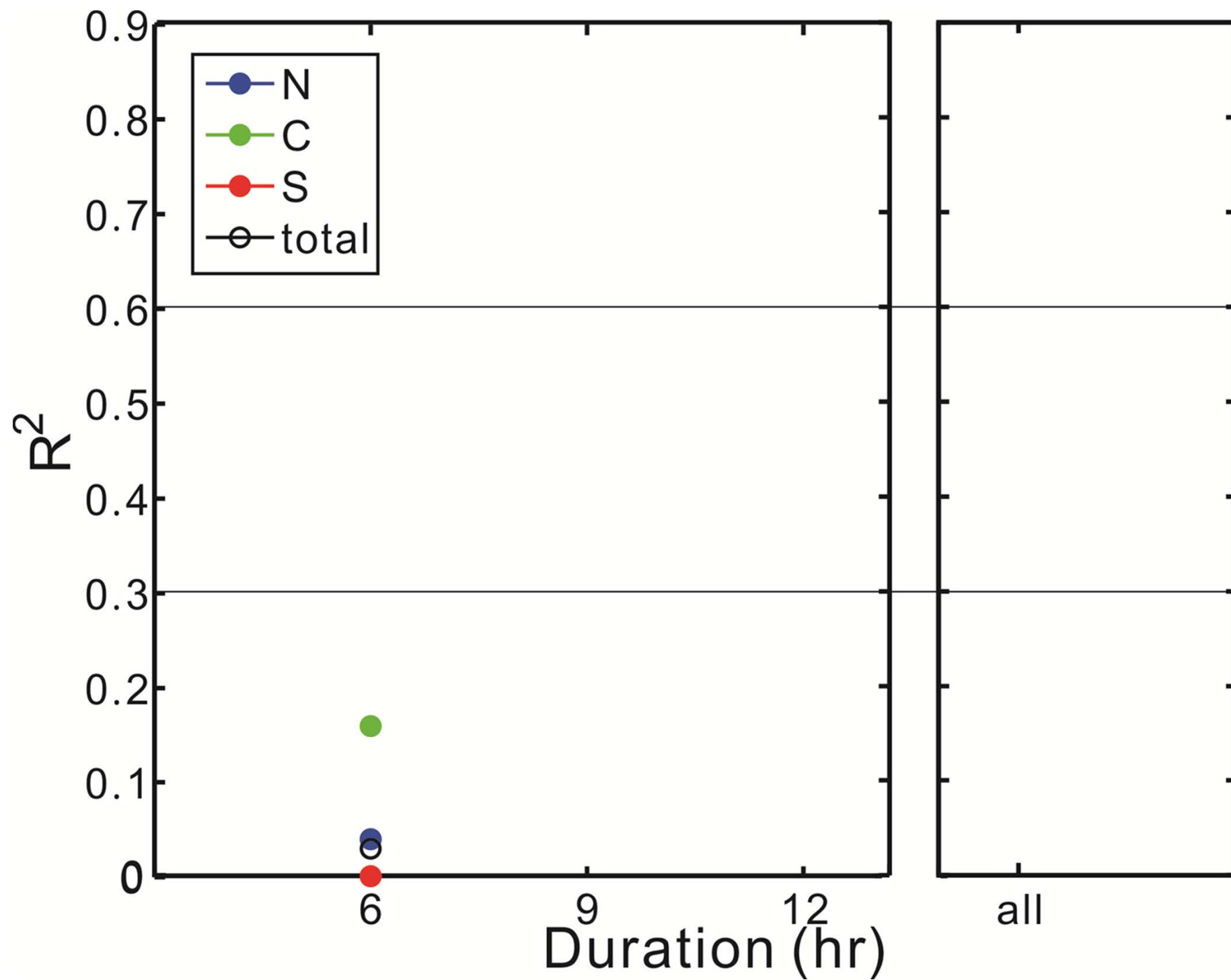


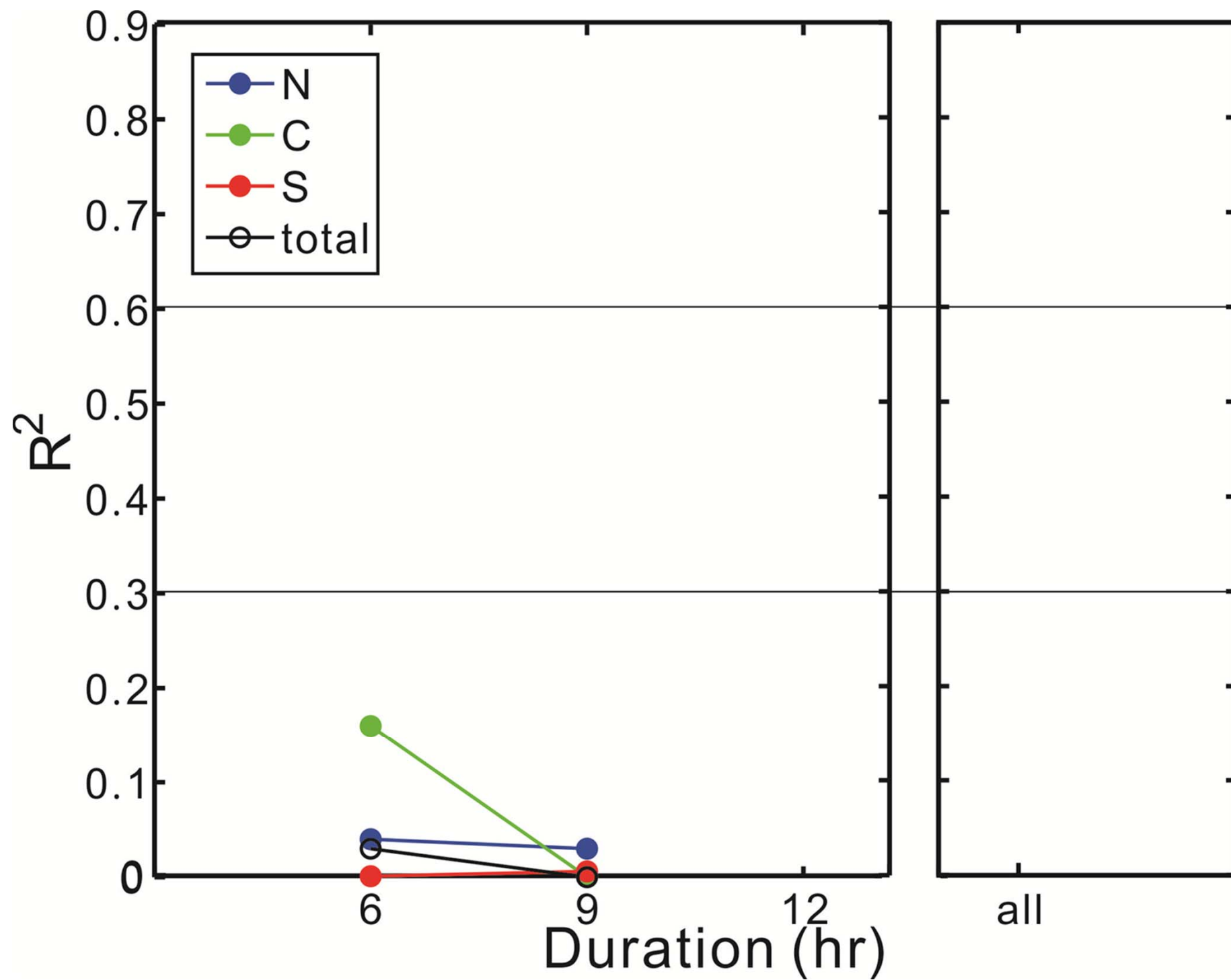


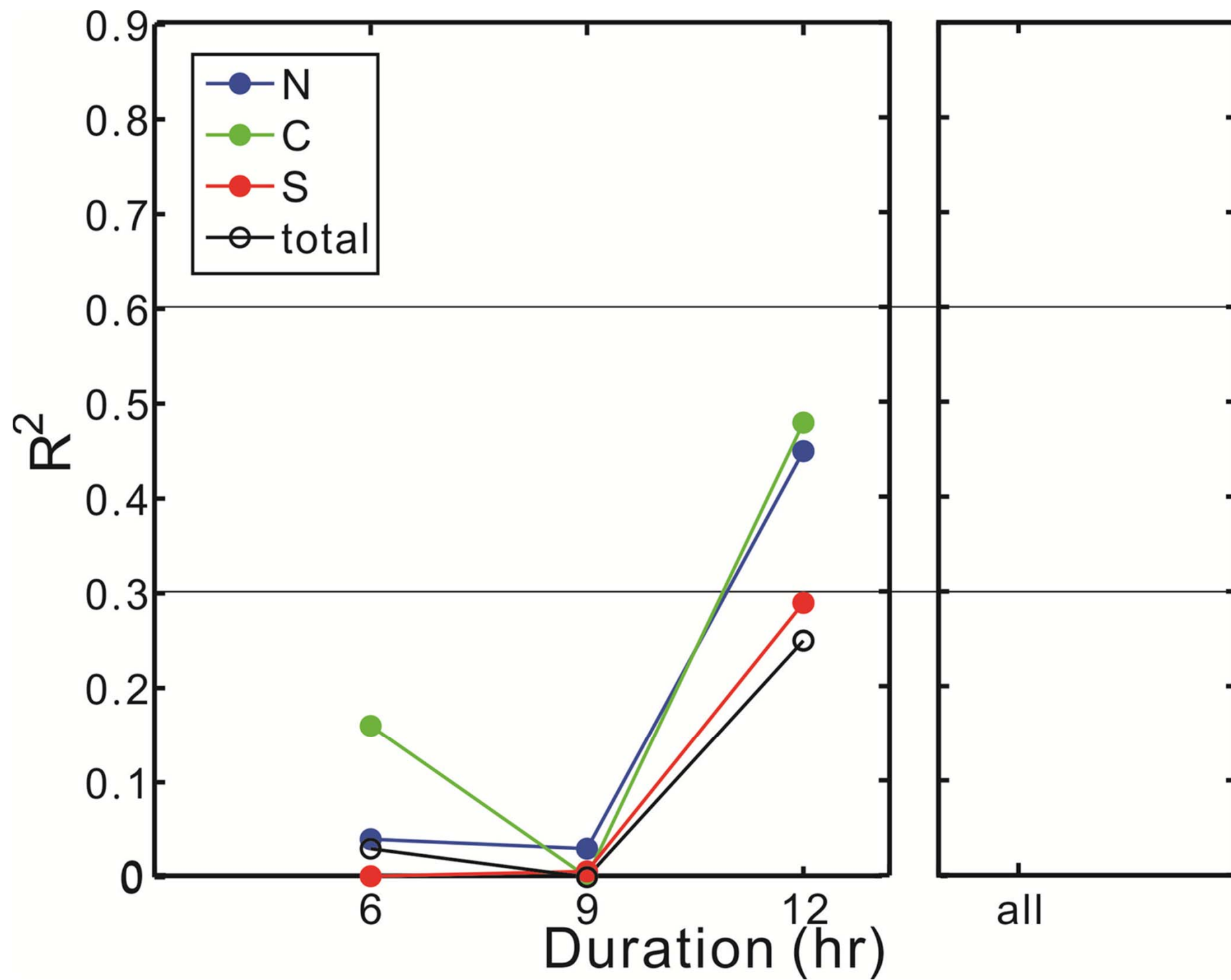




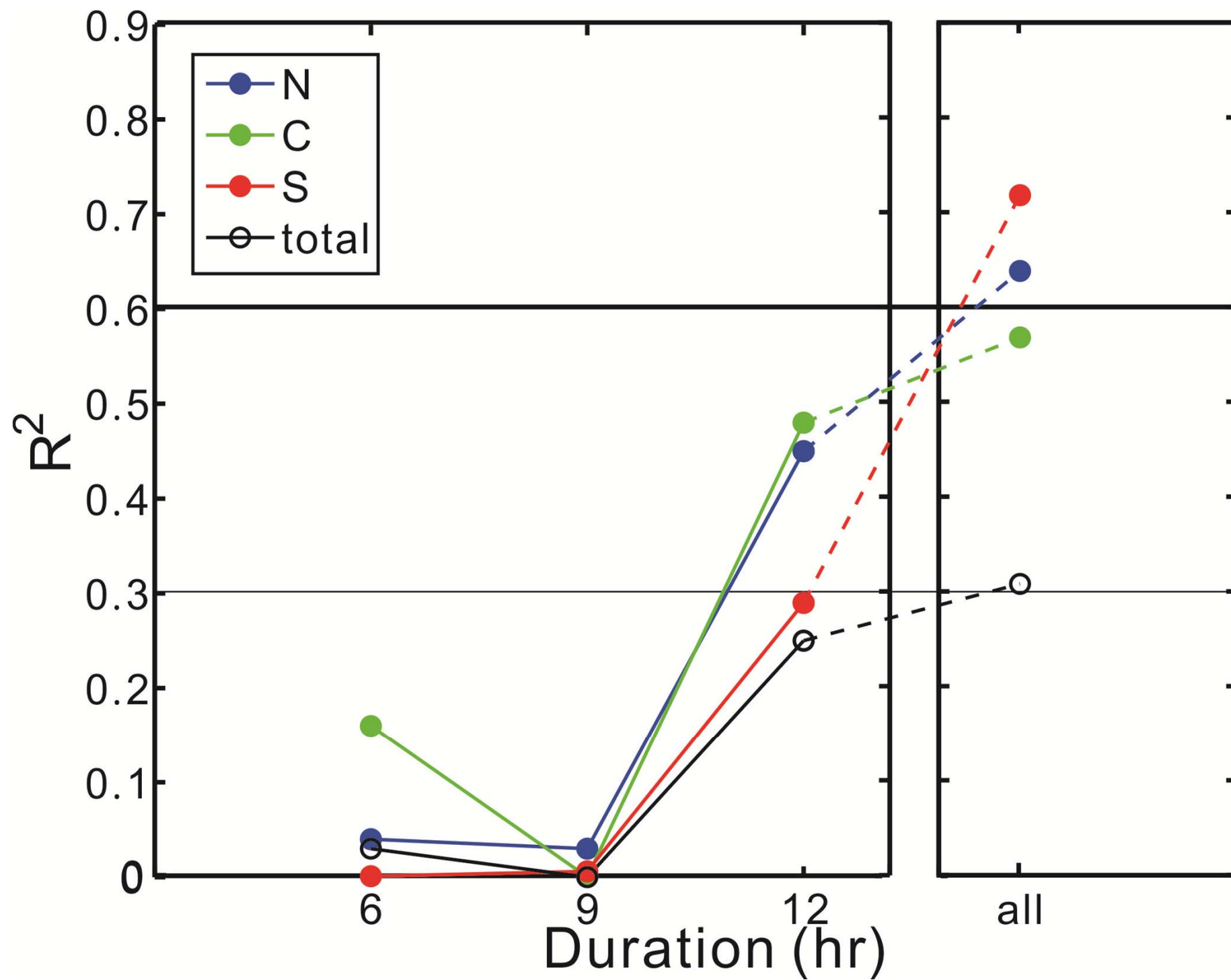




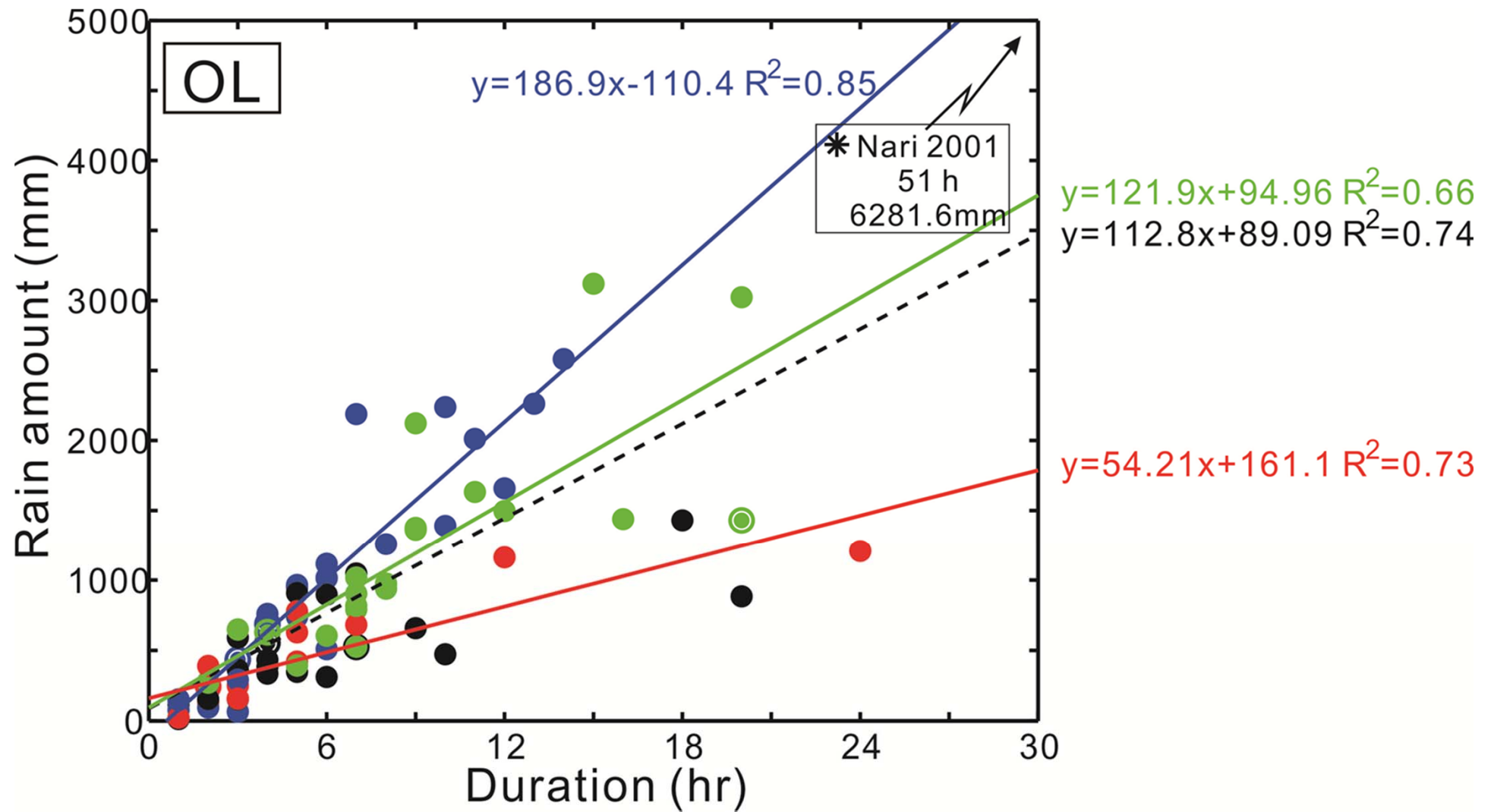


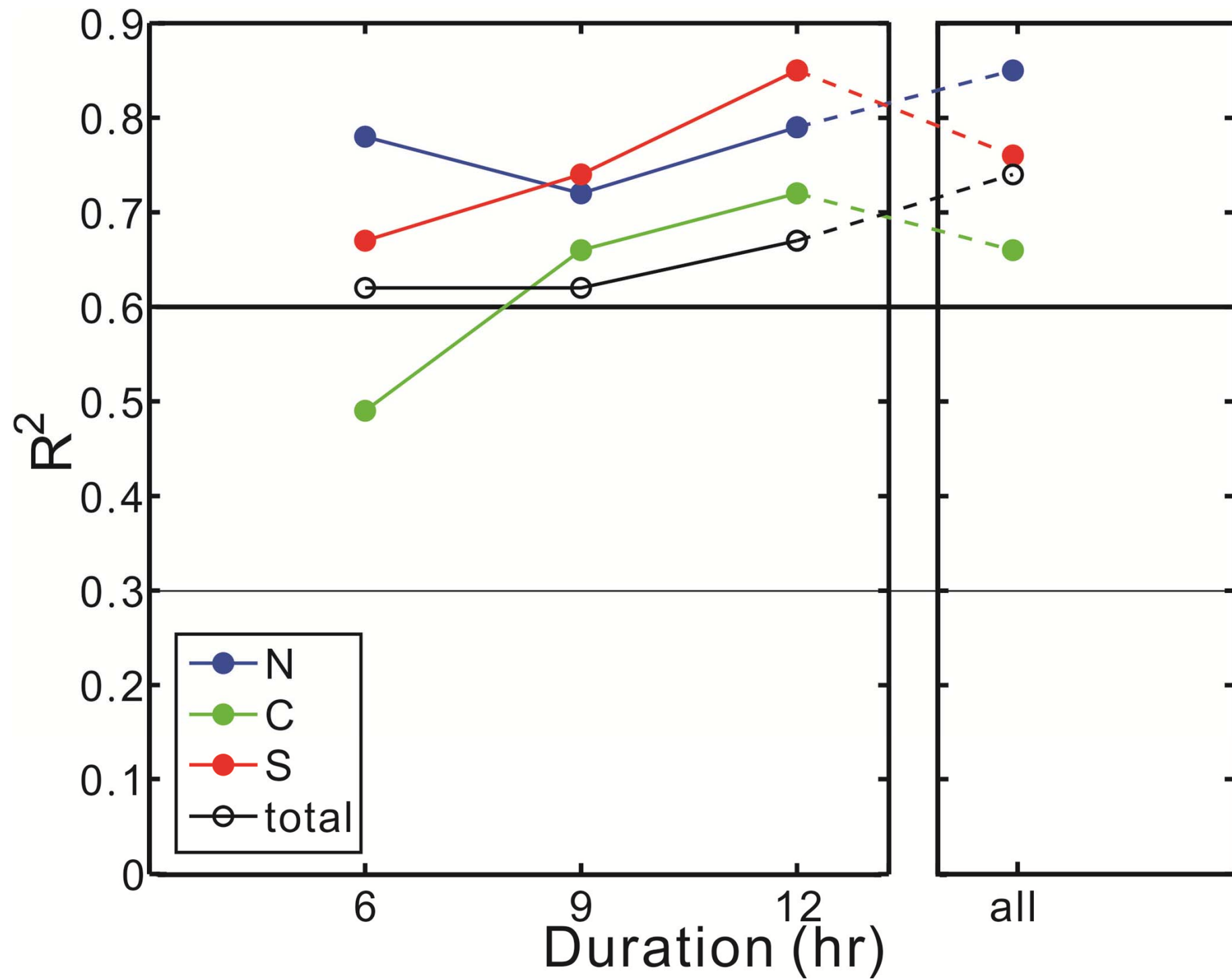






# Over-Land





EXit

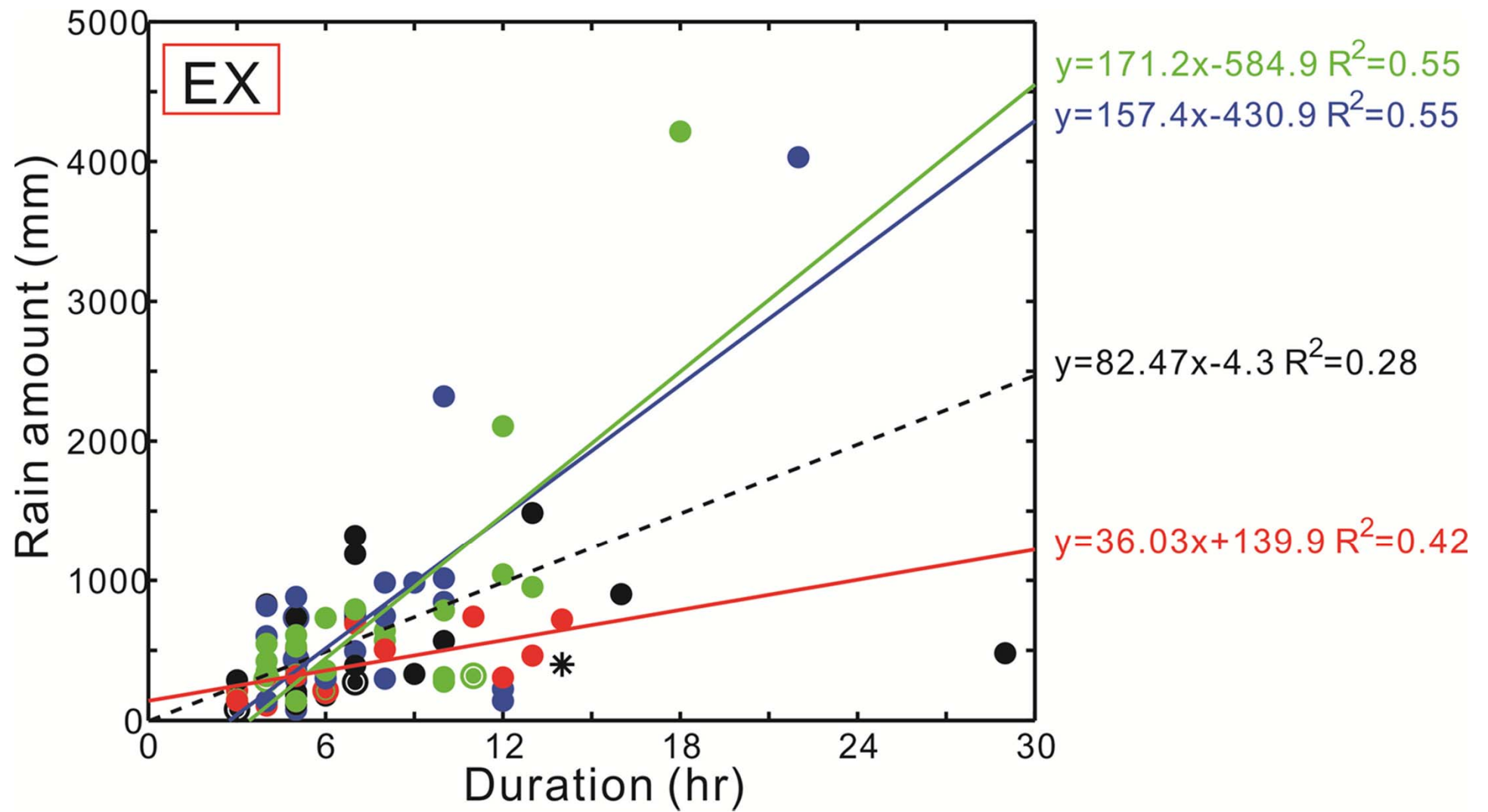


Table 2: The 12-hour rainfall intensity (mm) for the three track types during the three phases.

Phase	PR	OL	EX
Track Type			
N	1960	2132	1458
C	1305	1558	1467
S	1033	812	572

1. Terrain effect dominates
2. After exit, SW monsoon interaction important

Table 3: The absolute and relative (%) frequency and duration of the N, C, and S typhoons before and after 2004.

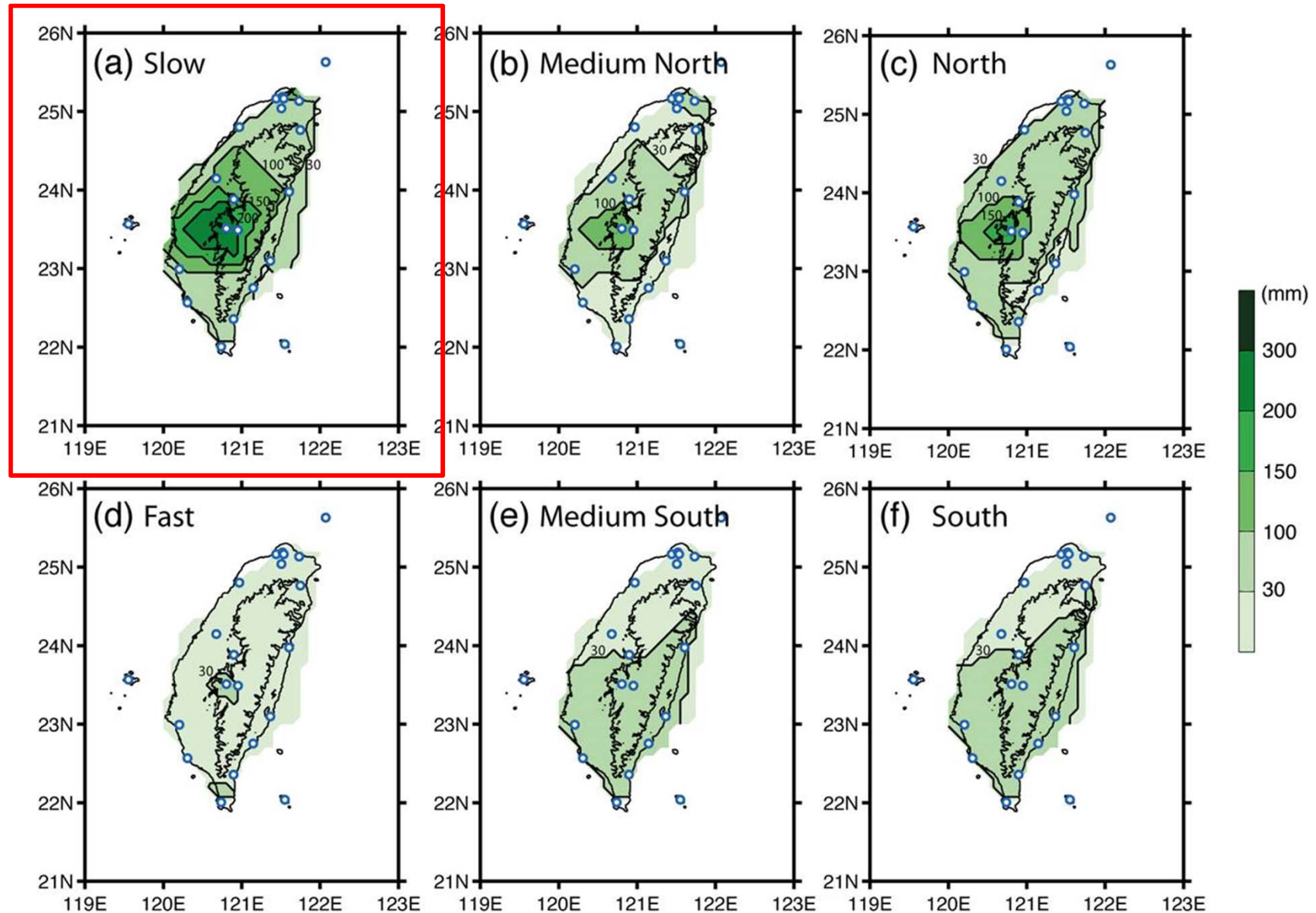
Frequency	1960-2003	2004-2011	
N	21(44.6%)	5(31.3%)	-1/3
C	15(31.9%)	8(50.0%)	+2/3
S	11(23.4%)	3(18.8%)	
Duration (hour)	1960-2003	2004-2011	
N	15.9	24.0	+1/2
C	23.9	23.3	
S	21.7	20.0	

(Chu, P.-S. et al., 2012, GRL: Slowing trend of NCEP/NCAR and ERA-40 steering flows from 1959 – 2009.)

*Total frequency +  
N duration +*

# Composite Rainfall

*N duration +*



*(Hsu, Kuo and Fovell 2013, JAS)*



## Decadal Rainfall Intensity Changes?

Fig 6a		
112.5	110.1	-2.1%
128.7	129.0	0.2%
78.2	92.9	18.8%
Fig. 6b		
112.2	112.1	-0.1%
128.8	130.4	1.2%
75.9	92.0	21.2%

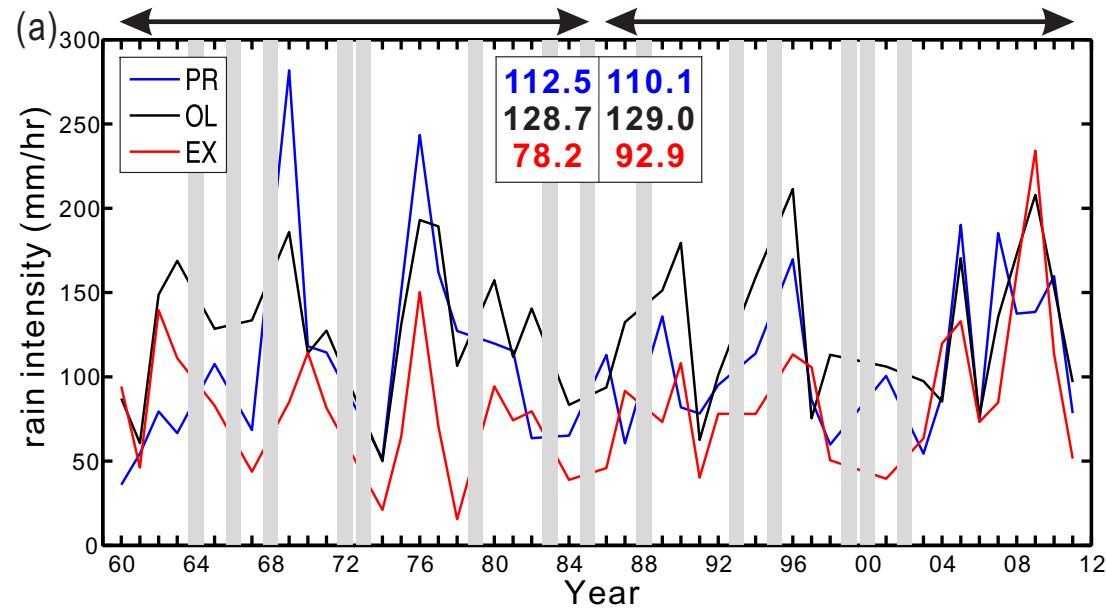


Figure 6. a) Time series of rainfall intensity from 1960 to 2011 for the pre-landing (PR, blue), overland (OL, black) and exit (EX, red) phases for weak and medium intensity (Category 1-3) typhoons. Grey vertical columns indicate years with no typhoons of the three leading track types. The table inside the panel lists the averaged yearly rainfall intensities of the three phases during the first half (1960-1985, left column) and second half (1986-2011, right column) of the 52 year period. The two sub-periods are indicated by double end arrows above the panel. b) Same as a) except strong types (Category 4-5) are included. The rainfall intensity of each strong typhoon is indicated by the respective colored dots.

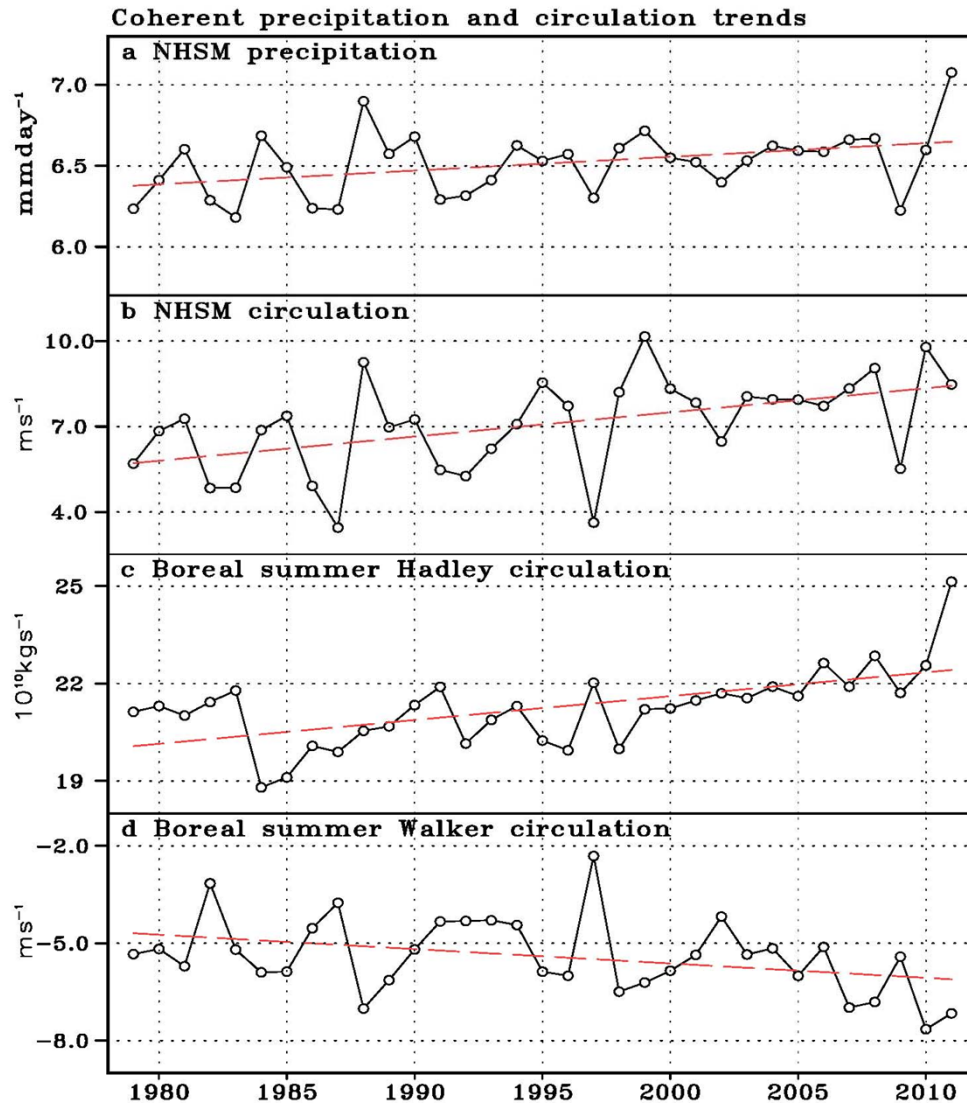
# Huge increase of TC rain signifies global warming/climate change effects?

- Pre-landfall and Over-land, the increase is due to longer duration and slight change of tracks.
  - Result of strong control by terrain effect (track change is mesoscale)
- After center exits Taiwan, increase due to stronger monsoon-TC interaction.
  - Link to global climate change possible: (but not TC intensity)

*Global Warming? or  
Natural Variability?*

## Global Warming or Natural Variability?

GW predicts **weakening** of tropical circulations.

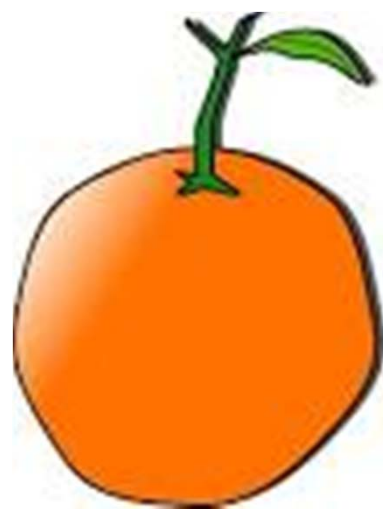


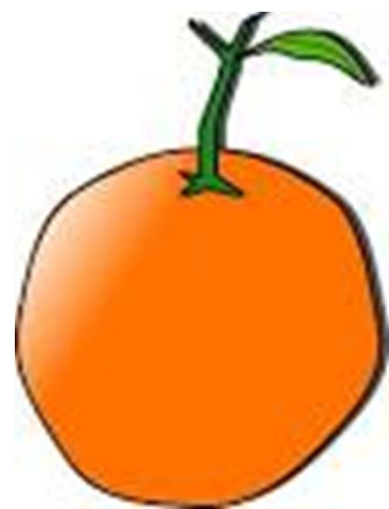
Strengthening of NH summer monsoon and tropical circulations consistent with slower steering flow of Taiwan TCs and enhanced monsoon interaction after TC leaves Taiwan.

(Wang, B. et al. 2013, PNAS)

# Conclusions

- Increasing extreme rainfall trend in Asian monsoon land area masked by decreasing TC rainfall activity. Taiwan is an exception.
  - Pre-landfall and Over-land, TC rainfall increase is due to longer duration and slight (mesoscale) change of tracks.
  - Local terrain effect contributes to an impression of climate change, yet it strongly constraints the rain intensity and masks broad scale climate change.
  - After center exits Taiwan, rainfall increase due to stronger monsoon-TC interaction.
    - Not positive feedback with TC intensity (decreased over the 50 years)
    - Inconsistent with anthropogenic global warming theories
    - Consistent with natural decadal variability of Mega ENSO and AMV (Wang et al. 2013)
- *Consistent with reduction of steering flow that caused the longer duration*







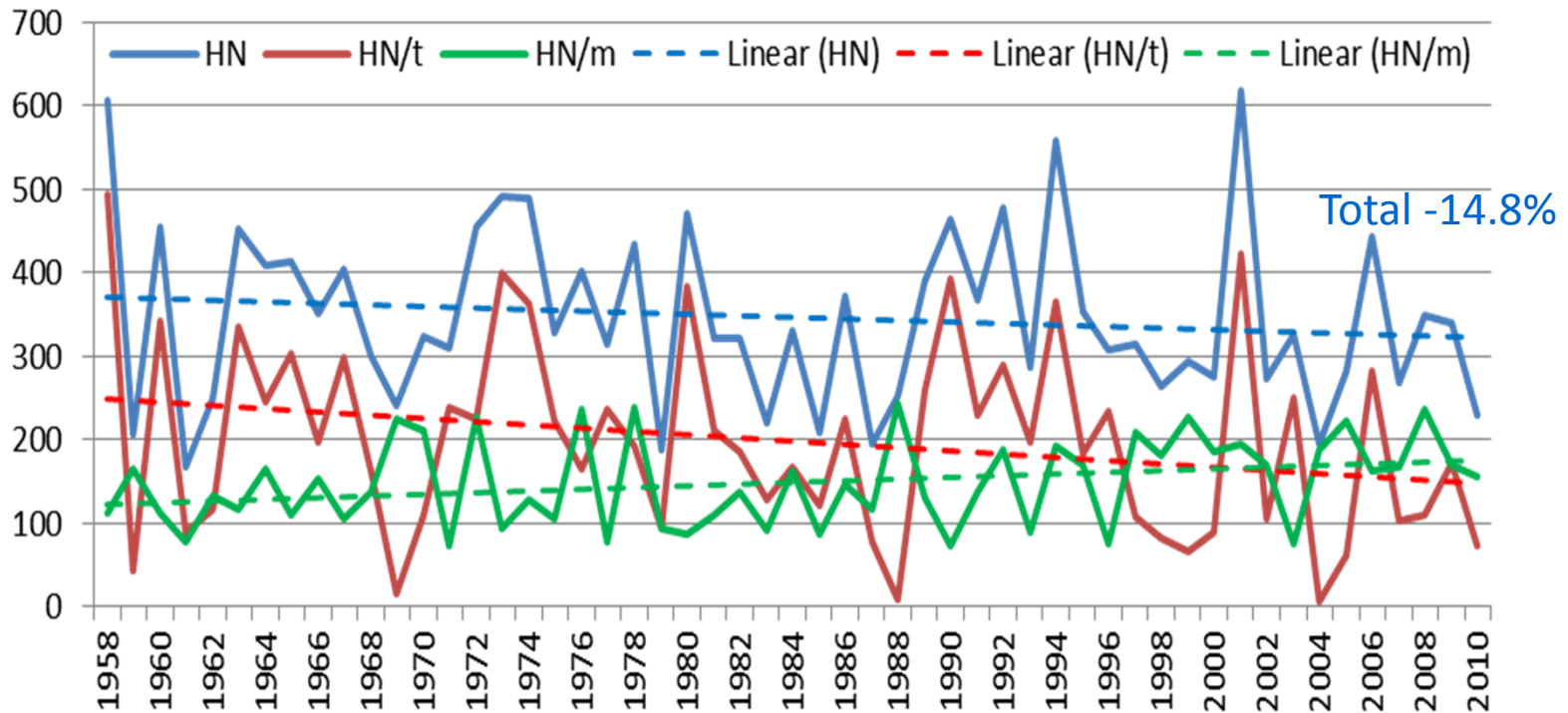


Thank You!

# Data

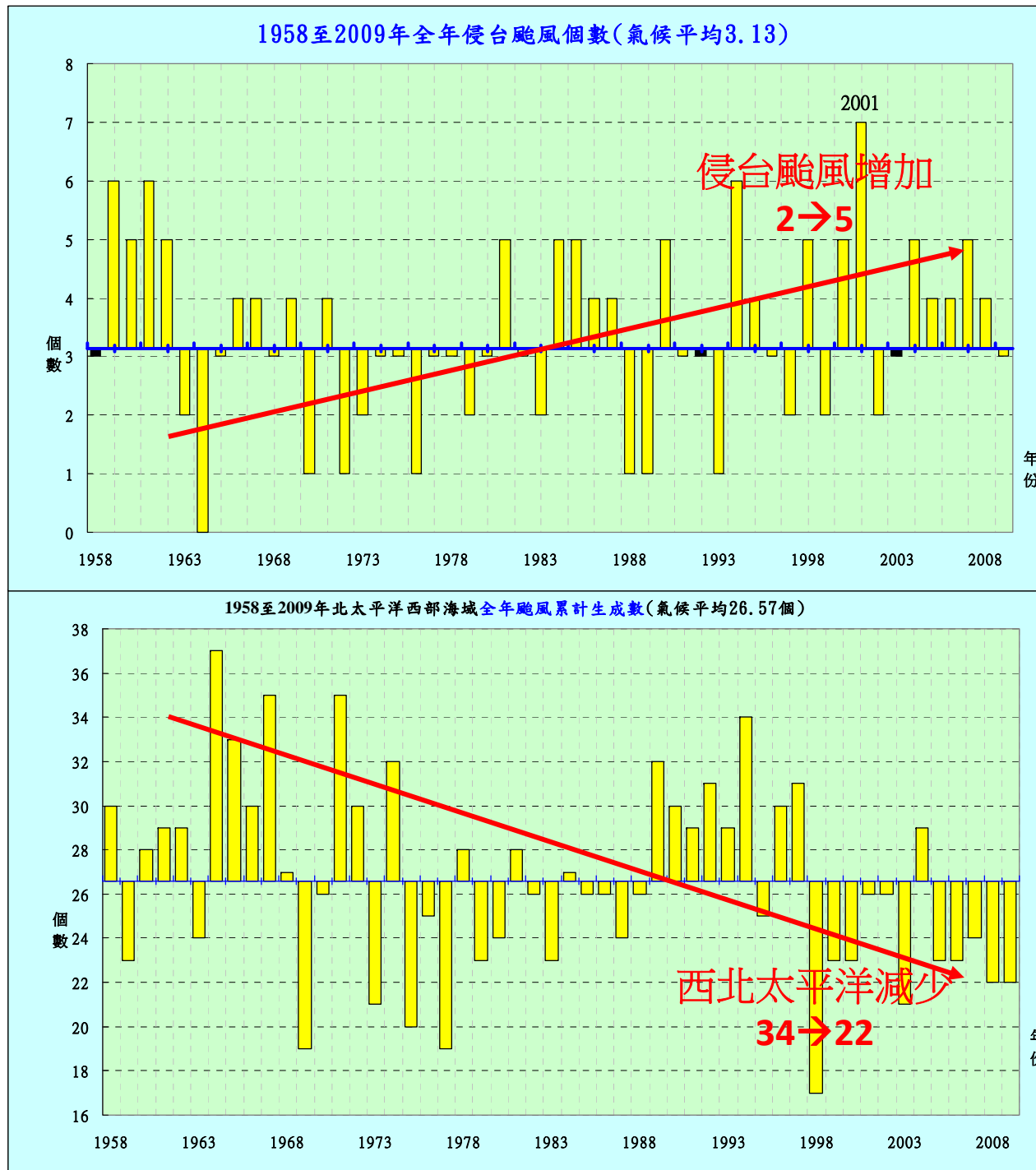
- JJA 1958-2010, 53 years.
- Daily rain stations: 479 (out of 776) from China mainland including Hainan Island, 20 from Taiwan;  $\geq 95\%$  complete.
- Extreme rainfall defined locally at 90<sup>th</sup> percentile.
- Each rain day is either TC or Monsoon (non-TC).
- TC events identified with Objective Synoptic Analysis Technique (OSAT, Ren *et al.*, 2006), Influence range 500-1100 km.

# Hainan 90<sup>th</sup> percentile



Monsoon +35.1%

Underestimate ∞



Total frequency +

(李清藤、賈新興，  
交通部中央氣象局)

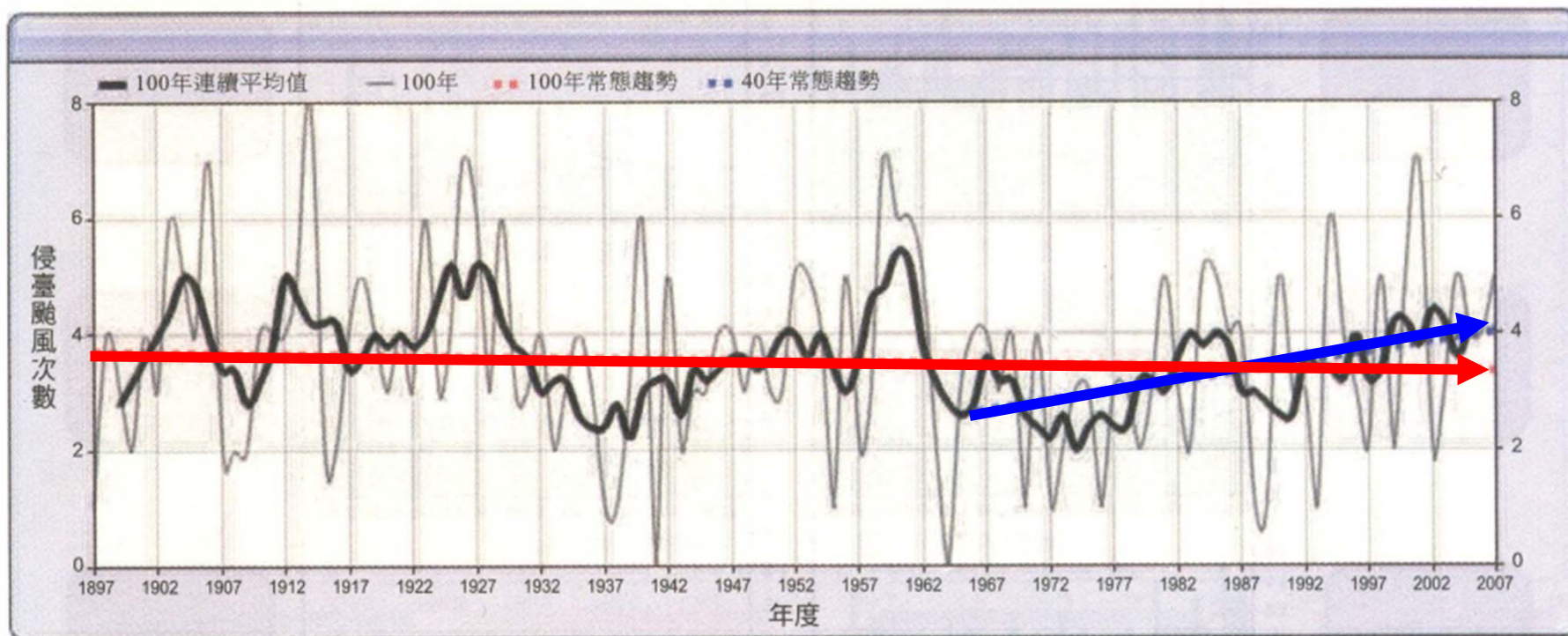


圖 2-5 臺灣地區近百年來侵臺颱風次數歷年變化圖

資料來源：李清滕、賈新興，〈颱風的長期氣候變遷〉，發表於「2008 臺灣氣候變遷」研討會（臺北：交通部中央氣象局，2008 年 8 月 25-26 日）。